SECTION 8.0
BENZENE EMISSIONS FROM MOBILE SOURCES

This section quantifies benzene as one component of mobile source hydrocarbon emissions. These emissions occur from mobile sources as evaporative emissions from carburetors, fuel tanks, and crankcases, and as a result of combustion.

Benzene is not added to vehicle fuels such as gasoline or diesel, but is formed during their manufacture, either through catalytic reforming or steam cracking. Most vehicle fuel is processed using catalytic reforming. In catalytic reforming, benzene is produced during the reaction that increases the octane rating of the naphtha fraction of the crude oil used as feedstock. Gasoline produced using this process is approximately 0.90 percent benzene (by weight).[158] (See Section 4.1 for an expanded discussion of catalytic reforming.)

The other vehicle fuel manufacturing process, the use of steam cracking of naphtha feedstock to obtain ethylene, yields gasoline with a higher benzene content--20 to 50 percent. This fuel is blended with other fuels, before it is sold, in order to comply with the limited maximum concentration of 1.3 percent (by volume). However, steam cracking is considered a minor source of vehicle fuel. (Refer to Section 4.3 for an expanded discussion of pyrolysis gasoline and ethylene plants.)

Diesel fuel, on the other hand, is produced by hydrocracking of the gas oil fraction of crude, and contains relatively insignificant amounts of benzene.

Benzene is emitted in vehicle exhaust as unburned fuel and as a product of combustion. Higher-molecular-weight aromatics in the fuel, such as ethylbenzene and toluene, can be converted to benzene as products of combustion, accounting for approximately 70 to 80 percent of the benzene in vehicle exhaust.

The fraction of benzene in the exhaust varies depending on vehicle type, fuel type, and control technology, but is generally between 3 to 5 percent by weight of the exhaust. The fraction of benzene in the evaporative emissions also depends on control technology and fuel composition, and is generally 1 percent of a vehicle's evaporative emissions.

8.1 ON-ROAD MOBILE SOURCES

Results of recent work by the Office of Mobile Sources (OMS) on toxic emissions from on-road motor vehicles are presented in the 1993 report *Motor Vehicle-Related Air Toxics Study* (MVATS).[20] This report was prepared in response to Section 202(l)(1) of the 1990 amended CAA, which directs EPA to complete a study of the need for, and feasibility of, controlling emissions of toxic air pollutants that are unregulated under the Act and are associated with motor vehicles and motor vehicle fuels. The report presents composite emission factors for several toxic air pollutants, including benzene.

The emission factors presented in the MVATS were developed using currently available emissions data in a modified version of the OMS's MOBILE4.1 emissions model (designated MOBTOX) to estimate toxic emissions as a fraction of total organic gas (TOG) emissions. TOG includes all hydrocarbons as well as aldehydes, alcohols, and other oxygenated compounds. All exhaust mass fractions were calculated on a vehicle-by-vehicle basis for six vehicle types: light-duty gasoline vehicles, light-duty gasoline trucks, heavy-duty gasoline trucks, light-duty diesel vehicles, light-duty diesel trucks, and heavy-duty diesel trucks.

OMS assumed that light-duty gas and diesel trucks have the same mass fractions as light-duty gas and diesel vehicles, respectively. In developing mass fractions for light-duty gas vehicles and trucks, four different catalytic controls and two different fuel systems (carbureted or fuel injection) were considered. Mass fractions for heavy-duty gas vehicles were developed for carbureted fuel systems with either no emission controls or a three-way catalyst. These mass fractions were applied to TOG emission factors developed to calculate in-use benzene emission factors. These in-use factors take into consideration evaporative and exhaust emissions as well as the effects of vehicle age.

A number of important assumptions were made in the development of these on-road benzene emission factors, namely:

1. The increase in emissions due to vehicle deterioration with increased mileage is proportional to the increase in TOG;
2. Toxics fractions remain constant with ambient temperature changes; and
3. The fractions are adequate to use for the excess hydrocarbons that come from malfunction and tampering/misfueling.

It should be noted that, in specific situations, EPA mobile methods may over or underestimate actual emissions.

The benzene emission factors by vehicle class in grams of benzene emitted per mile driven are shown in Table 8-1.[270] The OMS also performed multiple runs of the MOBTOX program to derive a pollutant-specific, composite emission factor that represented all vehicle classes, based on the percent of total vehicle miles traveled (VMT) attributable to each vehicle class.[20]

For traditional gasoline, benzene is typically responsible for 70 to 75 percent of the aggregated toxic emissions. Most of this is associated with engine combustion exhaust.

TABLE 8-1. BENZENE EMISSION FACTORS FOR 1990
TAKING INTO CONSIDERATION VEHICLE AGING (g/mi)

	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	Weighted VMT Mix
Exhaust										
Areas with no I/M	0.088	0.128	0.191	0.144	0.365	0.017	0.024	0.035	0.111	0.108
Areas with basic I/M	0.068	0.128	0.191	0.144	0.365	0.017	0.024	0.035	0.111	0.095
Evaporative	0.011	0.014	0.011	0.013	0.041	--	--	--	0.037	0.012
Refueling Loss	0.002	0.003	0.003	0.003	0.005	--	--	--	0.002	0.002
Running Loss	0.005	0.005	0.008	0.006	0.013	--	--	--	0.005	0.005
Resting Loss	0.001	0.001	0.001	0.001	0.001	--	--	--	0.004	0.001

LDGV = Light-Duty Gasoline Vehicle
LDGT1 = Light-Duty Gasoline Truck [pick-ups and vans with gross vehicle weight of 0 to 600 lb (0 to 272 kg)]
LDGT2 = Light-Duty Gasoline Truck [pick-ups and vans with gross vehicle weight of 601 to 8500 lb (273 to 3,856 kg)]
LDGT = Light-Duty Gasoline Truck (combined category of LDGT1 and LDGT2)
HDGV = Heavy-Duty Gasoline Vehicle
LDDV = Light-Duty Diesel Vehicle
LDDT = Light-Duty Diesel Truck
HDDV = Heavy-Duty Diesel Vehicle
MC = Motorcycle
-- = Not applicable

Oxygenated fuels emit less benzene than traditional gasoline mixes but more than diesel fuel. With the introduction of alternative fuels such as methanol blends, compressed natural gas (CNG), and liquified petroleum gas (LPG), formaldehyde is the dominant toxic emission, accounting for 80 to 90 percent of aggregated toxic emissions.[272] Reductions in benzene emissions associated with the use of methanol fuels is dependent upon the methanol content of the fuel. For instance, benzene emissions for M10 (10 percent methanol and 90 percent unleaded gasoline) are reduced by 20 percent compared with traditional fuel, and for M85 (85 percent methanol and 15 percent unleaded gasoline) the reduction is 84 percent (SAE1992). M100 (100 percent methanol), ethanol, LPG, and CNG emit minimal amounts of benzene.[273] Furthermore, because both LPG and CNG require closed delivery systems, evaporative emissions are assumed to be zero.

8.2 OFF-ROAD MOBILE SOURCES

For off-road mobile sources, EPA prepared the 1991 report *Nonroad Engine Vehicle Emission Study* (NEVES),[274] which presents emission factors for 79 equipment types, ranging from small equipment such as lawn mowers and chain saws to large agricultural, industrial, and construction machinery (see Table 8-2). The equipment types were evaluated based on three engine designs: two-stroke gasoline, four-stroke gasoline, and diesel. Sources for the data include earlier EPA studies and testing and new information on tailpipe exhaust and crankcase emissions supplied by the engine manufacturers. For test data on new engines, OMS made adjustments to better represent in-use equipment emissions taking into consideration evaporative emissions and increases in emissions due to engine deterioration associated with increased equipment age; therefore, new engine data underestimate in-use emissions.[274]

Although these emission factors were intended for calculating criteria pollutant (VOC, NO_2, CO) emissions for SIP emissions inventories, OMS derived emission factors for several HAPs, including benzene, so that national air toxics emissions could be estimated. To estimate benzene emissions, OMS expressed benzene emissions as a weight percent of exhaust

TABLE 8-2. OFF-ROAD EQUIPMENT TYPES AND HYDROCARBON EMISSION FACTORS INCLUDED IN THE NEVES (g/hp-hr)
(FACTOR QUALITY RATING E)

Equipment Type, Area and Mobile Source Code (2-stroke gas/4-stroke gas/diesel)	2-Stroke Gasoline Engines		4-Stroke Gasoline Engines		Diesel Engines	
	Exhaust	Crank Case	Exhaust	Crank Case	Exhaust	Crank Case
Lawn and Garden, 22-60/65/70-004-						
025 Trimmers/Edgers/Brush Cutters	471.58[a]	--	50.78[a]	7.98[a]	--	--
010 Lawn Mowers	436.80[a]	--	79.17[a]	12.44[a]	--	--
030 Leaf Blowers/Vacuums	452.11[a]	--	40.74[a]	6.40[a]	--	--
040 Rear-Engine Riding Mowers	--	--	19.53[a]	3.07[a]	1.20	0.02
045 Front Mowers	--	--	19.53[a]	3.07[a]	--	--
020 Chain Saws <4 hp	625.80[a]	--	--	--	--	--
050 Shredders <5 hp	436.80[a]	--	79.17[a]	12.44[a]	--	--
015 Tillers <5 hp	436.80[a]	--	79.17[a]	12.44[a]	--	--
055 Lawn and Garden Tractors	--	--	19.74[a]	3.10[a]	1.20	0.02
060 Wood Splitters	--	--	79.17[a]	12.44[a]	1.20	0.02
035 Snow Blowers	436.80[a]	--	79.17[a]	12.44[a]	--	--
065 Chippers/Stump Grinders	--	--	56.55[b]	12.44[b]	1.20	0.02
070 Commercial Turf Equipment	436.80[a]	--	19.74[a]	3.10[a]	--	--
075 Other Lawn and Garden Equipment	436.80[a]	--	79.17[a]	12.44[a]	1.20	0.02
Airport Service, 22-60/65/70-008-						
005 Aircraft Support Equipment	--	--	10.02[b]	2.20[b]	1.57[c]	0.03[c]
010 Terminal Tractors	4.50[b,d]	0.99[b,d]	10.02[b]	2.20[b]	1.57[c]	0.03[c]
Recreational, 22-60/65/70-001-						
030 All-Terrain Vehicles (ATVs)	1260.00[a,e]	--	210.00[a,e]	33.00[a,e]	--	--
040 Minibikes	--	--	210.00[a,e]	33.00[a,e]	--	--
010 Off-Road Motorcycles	1260.00[a,e]	--	150.00[b,e]	33.00[b,e]	--	--
050 Golf Carts	1260.00[a,e]	--	210.00[a,e]	33.00[a,e]	--	--
020 Snowmobiles	228.90[a]	--	--	--	--	--
060 Specialty Vehicles Carts	1260.00[a,e]	--	210.00[a,e]	33.00[a,e]	1.20[e]	0.02[e]

(continued)

TABLE 8-2. CONTINUED

Equipment Type, Area and Mobile Source Code (2-stroke gas/4-stroke gas/diesel)	2-Stroke Gasoline Engines		4-Stroke Gasoline Engines		Diesel Engines	
	Exhaust	Crank Case	Exhaust	Crank Case	Exhaust	Crank Case
Recreational Marine Vessels, 22-82-005/010/020-						
005 Vessels w/Inboard Engines	873.67[b,f]	--	108.69[b,f]	--	24.39[f]	--
010 Vessels w/Outboard Engines	873.67[b,f]	--	131.57[b,f]	28.94[b,f]	24.39[f]	0.49[f]
015 Vessels w/Sterndrive Engines	873.67[b,f]	--	108.69[b,f]	--	24.39[f]	--
020 Sailboat Auxiliary Inboard Engines	--	--	108.69[b,f]	--	122.45[f]	--
025 Sailboat Auxiliary Outboard Engines	873.67[b,f]	--	131.57[b,f]	28.94[b,f]	122.45[f]	2.45[f]
Light Commercial, less than 50 HP, 22-60/65/70-006-						
005 Generator Sets	436.80[a]	--	19.95[a]	3.14[a]	1.20	0.02
010 Pumps	8.99[a,d]	1.41[a,d]	19.95[a]	3.14[a]	1.20	0.02
015 Air Compressors	--	--	19.95[a]	3.14[a]	1.20	0.02
020 Gas Compressors	6.42[b,d]	1.41[b,d]	--	--	--	--
025 Welders	--	--	19.95[a]	3.14[a]	1.20	0.02
030 Pressure Washers	--	--	19.95[a]	3.14[a]	1.20	0.02
Industrial, 22-60/65/70-003-						
010 Aerial Lifts	4.50[b,d]	1.49[b,d]	10.02[b]	2.20[b]	1.57[c]	0.03[c]
102 Forklifts	4.50[b,d]	1.49[b,d]	10.02[b]	2.20[b]	1.57[c]	0.03[c]
030 Sweepers/Scrubbers	4.50[b,d]	1.49[b,d]	10.02[b]	2.20[b]	1.57[c]	0.03[c]
040 Other General Industrial Equipment	312.00[b]	--	10.02[b]	2.20[b]	1.57[c]	0.03[c]
050 Other Material Handling Equipment	--	--	10.02[b]	2.20[b]	1.57[c]	0.03[c]
Construction, 22-60/65/70-002-						
003 Asphalt Pavers	--	--	9.74[b]	2.14[b]	0.60	0.01
006 Tampers/Rammers	436.80[a]	--	13.63[a]	2.14[a]	0.00	0.00
009 Plate Compactors	436.80[a]	--	13.63[a]	2.14[a]	0.80	0.02
012 Concrete Pavers	--	--	--	--	1.10	0.02

(continued)

TABLE 8-2. CONTINUED

Equipment Type, Area and Mobile Source Code (2-stroke gas/4-stroke gas/diesel)	2-Stroke Gasoline Engines		4-Stroke Gasoline Engines		Diesel Engines	
	Exhaust	Crank Case	Exhaust	Crank Case	Exhaust	Crank Case
Construction, 22-60/65/70-002- (con't)						
015 Rollers	--	--	19.43[a]	3.05[a]	0.80	0.02
018 Scrapers	--	--	--	--	0.70[c]	0.01[c]
021 Paving Equipment	436.80[a]	--	13.63[a]	2.14[a]	1.01	0.02
024 Surfacing Equipment	--	--	13.63[a]	2.14[a]	0.00	0.00
027 Signal Boards	--	--	13.63[a]	2.14[a]	1.20	0.02
030 Trenchers	--	--	9.74[b]	2.14[b]	1.54[c]	0.03[c]
033 Bore/Drill Rigs	436.80[a]	--	9.74[b]	2.14[b]	1.41[c]	0.03[c]
036 Excavators	--	--	9.74[b]	2.14[b]	0.70[c]	0.01[c]
039 Concrete/Industrial Saws	--	--	13.63[a]	2.14[a]	1.41[c]	0.03[c]
042 Cement and Mortar Mixers	--	--	13.63[a]	2.14[a]	1.01	0.02
045 Cranes	--	--	9.74[b]	2.14[b]	1.26[c]	0.03[c]
048 Graders	--	--	--	--	1.54[c]	0.03[c]
051 Off-Highway Trucks	--	--	--	--	0.84[c]	0.02[c]
054 Crushing/Proc. Equipment	--	--	9.74[b]	2.14[b]	1.41[c]	0.03[c]
057 Rough Terrain Forklifts	--	--	9.74[b]	2.14[b]	1.68[c]	0.03[c]
060 Rubber Tire Loaders	--	--	8.34[b]	1.83[b]	0.84[c]	0.02[c]
063 Rubber Tire Dozers	--	--	--	--	0.84[c]	0.02[c]
066 Tractors/Loaders/Backhoes	--	--	9.74[b]	2.14[b]	1.40[c]	0.03[c]
069 Crawler Tractors	--	--	--	--	1.26[c]	0.03[c]
072 Skid Steer Loaders	--	--	9.74[b]	2.14[b]	2.10[c]	0.04[c]
075 Off-Highway Tractors	--	--	--	--	2.46[c]	0.05[c]
078 Dumpers/Tenders	--	--	13.63[a]	2.14[a]	0.84[c]	0.02[c]
081 Other Construction Equipment	--	--	9.74[b]	2.14[b]	1.41[c]	0.03[c]
Agricultural, 22-60/65/70-005-						
010 2-Wheel Tractors	--	--	11.53[a]	1.81[a]	--	--
015 Agricultural Tractors	--	--	8.24[b]	1.81[b]	2.23[c]	0.04[c]
030 Agricultural Mowers	--	--	15.06[a]	2.37[a]	--	--
020 Combines	--	--	10.77[b]	2.37[b]	1.26[c]	0.03[c]
035 Sprayers	--	--	10.77[b]	2.37[b]	2.23	0.04

(continued)

TABLE 8-2. CONTINUED

Equipment Type, Area and Mobile Source Code (2-stroke gas/4-stroke gas/diesel)	2-Stroke Gasoline Engines		4-Stroke Gasoline Engines		Diesel Engines	
	Exhaust	Crank Case	Exhaust	Crank Case	Exhaust	Crank Case
Agricultural, 22-60/65/70-005- (con't)						
025 Balers	--	--	--	--	2.23	0.04
040 Tillers >5 hp	--	--	79.17[a]	12.44[a]	1.20	0.02
045 Swathers	--	--	10.77[b]	2.37[b]	0.90	0.02
050 Hydro Power Units	--	--	15.08[a]	2.37[a]	2.23	0.04
055 Other Agricultural Equipment	--	--	10.77[b]	2.37[b]	1.82	0.04
Logging, 22-60/65/70-007-						
005 Chain Saws >4 hp	319.20[a]	--	--	--	--	--
010 Shredders >5 hp	--	--	19.53[a]	3.07[a]	--	--
015 Skidders	--	--	--	--	0.84[c]	0.02[c]
020 Fellers/Bunchers	--	--	--	--	0.84[c]	0.02[c]

[a] Adjusted for in-use effects using small utility engine data.
[b] Adjusted for in-use effects using heavy-duty engine data.
[c] Exhaust HC adjusted for transient speed and/or transient load operation.
[d] Emission factors for 4-stroke propane-fueled equipment.
[e] g/hr.
[f] g/gallon.

"--" = Not applicable.

hydrocarbons plus crank case hydrocarbons. In OMS's analysis, it was assumed that the weight percent of benzene for all off-road sources was 3 percent of exhaust hydrocarbons.[275] A range of OMS-recommended weight percent benzene factors for general categories of off-road equipment are presented in Table 8-3.[274] Note that development of equipment-specific emission factors is underway, and when available, those emission factors should be considered instead. To obtain benzene emission estimates from equipment in these general categories of off-road equipment, the benzene weight percent factors noted in Table 8-3 can be applied to hydrocarbon estimates from the different NEVES equipment types.

The NEVES equipment emission factors can be used directly to estimate emissions from specific equipment types if local activity data is available. If general nonroad emission estimates are required, States may choose one of the 33 nonattainment areas, studied in the NEVES report, that is similar in terms of climate and economic activity; the NEVES nonattainment area can be adjusted to estimate emissions in another state by applying a population ratio of the two areas to the NEVES estimate. The NEVES report also has estimates for individual counties of the 33 nonattainment areas such that States or local governments may also produce regional or county inventories by adjusting the NEVES county estimates relative to the population of the different counties. Counties can be chosen from several of the 33 NEVES nonattainment areas if appropriate. For further details on how to calculate emissions from specific equipment types refer to NEVES, for details on calculating emissions of nonroad sources in general see Reference 271.

8.3 MARINE VESSELS

For commercial marine vessels, the NEVES report includes VOC emissions for six nonattainment areas taken from a 1991 EPA study *Commercial Marine Vessel Contribution to Emission Inventories*.[276] This study provided hydrocarbon emission factors for ocean-going commercial vessels and harbor and fishing vessels. The emission factors are shown in Table 8-4.

TABLE 8-3. WEIGHT PERCENT FACTORS FOR BENZENE

As Tested Use	Recommended Off-Road Category	Benzene % by Weight of FID HC[a]
Diesel Forklift Engine	Large Utility Equipment	2.4-3.0
Direct Injection Diesel Automobile	Large Utility Equipment (Cyclic) Construction Equipment	3.1-6.5
Indirect Injection Diesel Automobile	Large Utility Equipment (Cyclic) Marine, Agricultural Large Utility Construction Equipment	1.5-2.1
Leaded Gasoline Automobiles	Large Utility Equipment (Cyclic) Marine, Agricultural, Large Utility	3.0-3.4
Leaded Gasoline Automobiles (12% Misfire)	Large Utility Equipment (Cyclic) Marine, Agricultural, Large Utility	1.1-1.3
1973 Highway Traffic		3.0

Source: Reference 274.

[a] FID HC=Hydrocarbons measured by Flame Ionization Detection.

Ocean-going marine vessels fall into one of two categories--those with steam propulsion and those with motor propulsion. Furthermore, they emit pollution under two modes of operation: underway and at dockside (hotelling). Most steamships use boilers rather than auxiliary diesel engines while hotelling. Currently, there are no benzene toxic emission fractions for steamship boiler burner emissions. The emission factors for motor propulsion systems are based on emission fractions for heavy-duty diesel vehicle engines. For auxiliary diesel generators, emission factors are available only for 500 KW engines, since the 1991 Booz-Allen and Hamilton report indicated that almost all generators were rated at 500 KW or more.

For harbor and fishing vessels, benzene emission factors for diesel engines are provided for the following horsepower categories -- less than 500 hp, 500 to 1,000 hp, 1,000 to 1,500 hp, 1,500 to 2,000 hp, and greater than 2,000 hp. In each of these categories, emission factors are developed for full, cruise, and slow operating modes. Toxic emission

TABLE 8-4. BENZENE EMISSION FACTORS FOR COMMERCIAL MARINE VESSELS

Operating Plant (operating mode/rated output)	Benzene Emission Factor (lb/1000 gal fuel)[a]
Ocean-Going Commercial	
Motor Propulsion	
All underway modes	0.25
Auxiliary Diesel Generators	
500 KW (50% load)	0.87
Harbor and Fishing	
Diesel Engines	
<500 hp	
Full	0.22
Cruise	0.54
Slow	0.60
500-1000 hp	
Full	0.25
Cruise	0.18
Slow	0.18
1000-1500 hp	
Full	0.25
Cruise	0.25
Slow	0.25
1500-2000 hp	
Full	0.18
Cruise	0.25
Slow	0.25
2000+ hp	
Full	0.23
Cruise	0.18
Slow	0.24
Gasoline Engines - all hp ratings	
Exhaust (g/bhp-hr)	0.35
Evaporative (g/hr)	0.64

[a] Benzene exhaust emission factors were estimated by multiplying HC emission factors by benzene TOG fractions. Benzene exhaust emission fractions of HC for all marine diesel engines were assumed to be the same as the TOG emission fraction for heavy-duty diesel vehicles -- 0.0106. The benzene exhaust emission fraction for marine gasoline engines was assumed to be the same as the exhaust TOG emission fraction for heavy duty gasoline vehicles -- 0.0527. The benzene evaporative emission fraction was also assumed to be the same as the evaporative emission HC fraction for heavy duty gasoline vehicles -- 0.0104.

factors are also provided for gasoline engines in this category. These emission factors are not broken down by horsepower rating, and are expressed in grams per brake horsepower hour rather than pounds per thousand gallons of fuel consumed.

8.4 LOCOMOTIVES

As noted in the U.S. EPA's *Procedures for Emission Inventory Preparation,* Volume IV: Mobile Sources,[271] locomotive activity can be defined as either line haul or yard activities. Line haul locomotives, which perform line haul operation, generally travel between distant locations, such as from one city to another. Yard locomotives, which perform yard operations, are primarily responsible for moving railcars within a particular railway yard.

The OMS has included locomotive emissions in its *Motor Vehicle-Related Air Toxic Study*.[20] The emission factors used for locomotives in this report are derived from the heavy-duty diesel on-road vehicles as there are no emission factors specifically for locomotives. To derive toxic emission factors for heavy diesel on-road vehicles, hydrocarbon emission factors were speciated. The emission factors provided in this study (shown in Table 8-5) are based on g/mile traveled.[20]

TABLE 8-5. BENZENE EMISSION FACTORS FOR LOCOMOTIVES

Source	Toxic Emission Fraction	Emission Factor (lb/gal)
Line Haul Locomotive	0.0106[a]	0.00022
Yard Locomotive	0.0106[a]	0.00054

Source: Reference 20.

[a] These fractions are found in Appendix B6 of EPA, 1993, and represent toxic emission fractions for heavy-duty diesel vehicles. Toxic fractions for locomotives are assumed to be the same, since no fractions specific for locomotives are available. It should be noted that these fractions are based on g/mile emissions data, whereas emission factors for locomotives are estimated in lb/gal. The toxic emission fractions were multiplied by the HC emission factors to obtain the toxic emission factors.

8.5 AIRCRAFT

There are two main types of aircraft engines in use: turbojet and piston. A kerosene-like jet fuel is used in the jet engines, whereas aviation gasoline with a lower vapor pressure than automotive gasoline is used for piston engines. The aircraft fleet in the United States numbers about 198,000, including civilian and military aircraft.[277] Most of the fleet is of the single- and twin-engine piston type and is used for general aviation. However, most of the fuel is consumed by commercial jets and military aircraft; thus, these types of aircraft contribute more to combustion emissions than does general aviation. Most commercial jets have two, three, or four engines. Military aircraft range from single or dual jet engines, as in fighters, to multi-engine transport aircraft with turbojet or turboprop engines.[278]

Despite the great diversity of aircraft types and engines, there are considerable data available to aid in calculating aircraft- and engine-specific hydrocarbon emissions, such as the database maintained by the Federal Aviation Administration (FAA) Office of Environment and Energy, FAA Aircraft Engine Emissions Database (FAEED). These hydrocarbon emission factors may be used with weight percent factors of benzene in hydrocarbon emissions to estimate benzene emissions from this source. Benzene weight percent factors in aircraft hydrocarbon emissions are reported in an EPA memorandum [280] concerning toxic emission fractions for aircraft, and are presented in Table 8-6.

TABLE 8-6. BENZENE CONTENT IN AIRCRAFT LANDING AND TAKEOFF EMISSIONS

Description	AMS Code	Weight Percent Benzene	Factor Quality
Military Aircraft	22-75-001-000	2.02	B
Commercial Aircraft	22-75-020-000	1.94	B
Air Taxi Aircraft	22-75-060-000	3.44	C
General Aviation	22-75-050-000	3.91	C

Source: Reference 279 and 280.

Current guidance from EPA for estimating hydrocarbon emissions from aircraft appears in *Procedures for Emission Inventory Preparation*, Volume IV: Mobile Sources.[271] The landing/takeoff (LTO) cycle is the basis for calculating aircraft emissions. The operating modes in an LTO cycle are (1) approach, (2) taxi/idle in, (3) taxi/idle out, (4) takeoff, and (5) climbout. Emission rates by engine type and operating mode are given in the FAEED. To use this procedure, the aircraft fleet must be characterized and the duration of each operating mode determined. From this information, hydrocarbon emissions can be calculated for one LTO for each aircraft type in the fleet. To determine total hydrocarbon emissions from the fleet, the emissions from a single LTO for the aircraft type would be multiplied by the number of LTOs for each aircraft type.

The emission estimation method noted above is the preferred approach as it takes into consideration differences between new and old aircraft. If detailed aircraft information is unavailable, hydrocarbon emission indices for representative fleet mixes are provided in the emissions inventory guidance document *Procedures for Emissions Inventory Preparation*; Volume IV: Mobile Sources.[271] The hydrocarbon emission indices are 0.394 pounds per LTO (0.179 kg per LTO) for general aviation and 1.234 pounds per LTO (0.560 kg per LTO) for air taxis.

The benzene fraction of the hydrocarbon total (in terms of total organic gas) can be estimated by using the percent weight factors from Table 8-6. Because air taxis have larger engines and more of the fleet is equipped with turboprop and turbojet engines than is the general aviation fleet, the percent weight factor is somewhat different from the general aviation emission factor.

8.6 ROCKET ENGINES

Benzene has also been detected from rocket engines tested or used for space travel. Two types of rocket engines are currently in use: sustainer rocket engines, which provide the main continual propulsion, and booster rocket engines, which provide additional force at critical stages of the lift off, such as during the separation of sections of the rocket fuselage.

Source testing of booster rocket engines using RP-1 (kerosene) and liquid oxygen have been completed at an engine test site. Tests for benzene were taken for eight test runs sampling at four locations within the plume envelope below the test stand. Results from these tests yielded a range of benzene emission factors--0.31 to 0.561 lb/ton (0.155 to 0.280 kg/Mg) of fuel combusted--providing an average emission factor of 0.431 lb/ton (0.215 kg/Mg) of fuel combusted, as presented in Table 8-7.[282] It should be noted that booster fuel consumption is approximately five times that of sustainer rocket engines.

TABLE 8-7. EMISSION FACTORS FOR ROCKET ENGINES

AMS Code	Emissions Source	Emission Factor lb/ton (kg/Mg)	Factor Rating
28-10-040-000	Booster rocket engines using RP-1 (kerosene) and liquid oxygen as fuel	0.431 (0.215)[a]	C

Source: Reference 282.

[a] Emission factors are in lb (kg) of benzene emitted per ton (Mg) of fuel combusted.